

Advancing Predictive Models of Marine Sediment Transport Over Intermediate to Long Time Scales

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LONG-TERM GOAL

My long-term goal within the STRATAFORM program is to increase our understanding of the processes controlling the formation, reworking and preservation of event-scale stratigraphy on the continental shelf. My goal in the last phase of STRATAFORM is to extend our capability for modeling shelf sediment transport to time scales appropriate for models of the geologic evolution of continental margins (e.g., SEDFLUX and SEQUENCE).

OBJECTIVES

The objectives of this project for FY01 have been to 1) use available data to characterize forcing over longer time-scales (especially the time scale of 100's of years); 2) to provide a shelf sediment transport module to SEDFLUX based on a distributed version of my 1D model and to work on simpler, more parameterized representations of shelf processes appropriate for the SEQUENCE model; and 3) apply our coupled resuspension-flocculation-consolidation model to transport events on the Eel shelf.

APPROACH

My approach combines model development and application with data analysis to better understand shelf sediment transport processes, facilitate data analysis, and improve our predictive capabilities. This approach yields insights into transport and bed processes at time scales of events, decades to a hundred years (~ period of record), and geological time scales (1000's years or more).

WORK COMPLETED

1) I have extended my one-dimensional shelf sediment transport model to calculate 2-D (across- or along-shelf) changes in bed elevation and sediment size. This model is being incorporated into SEDFLUX and is being compared with other shelf transport formulations in SEDFLUX. The model adjusts bed elevation and texture on an event basis, given wave, current and sediment conditions. I have continued work with Pratson and Paola on a simple margin model that includes shelf processes, and have demonstrated that wave shoaling does not significantly contribute to shelf slopes except in the nearshore zone. My Geoclutter annual report describes work completed on characterizing shelf sediment diffusivity based on available wave and current time series for the Eel and other shelves. These diffusivities can be used to represent shelf processes in longer-term shelf evolution models.

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2) Michael Mann and I have begun to identify decadal-scale variations in oceanographic forcing conditions using existing data and to develop methods for downscaling from global-scale climate analyses to the local forcing necessary for shelf transport modeling. We are using NOAA buoy data and NCEP (National Centers for Environmental Prediction) climate reanalysis in these initial efforts.

3) Joel Carr and I have an operational model that calculates resuspension of fine-grained sediment including effects of flocculation in the water column, bed consolidation, and the evolution of the upper portion of the seabed as a result of these processes. This model was initially coded in Matlab but has now been translated into Fortran-90 for faster execution and better portability. This model has been applied to transport events on the Eel shelf during periods of high and low river discharge.

RESULTS

Modeling cross-shelf sediment redistribution over longer time scales

The need has been identified in both the SEDFLUX and SEQUENCE models for better representations of shelf processes. Most available shelf sediment transport models operate on time scales too short for models of the stratigraphic evolution of continental margins. During the past year I have worked on three models for representing shelf processes in long-term models. The first model is a version of my one-dimensional shelf model, in which the 1D model is run over a set of points (representing, e.g., a cross-shelf transect) to estimate vertically averaged net sediment flux at each point following a transport event. The cross-shelf divergence of the flux, calculated for each grain size in the bed, is then used to calculate net erosion (or deposition) and a new grain size distribution at each point. The second model is based on sediment diffusivities on the continental shelf. Existing wave and current data are used to determine diffusivities as a function of water depth for the sediment sizes present on a shelf. This model is described in my ONR Geoclutter annual report. The third model is a simple margin model I have been working on with Lincoln Pratson and Chris Paola. This year I have incorporated effects of wave shoaling, consolidation and subsidence to examine controls on shelf slope.

The cross-shelf, event-based transport model is an extension of an existing 1D shelf sediment transport model. The 1D model is run for a cross-shelf grid of nodes of specified depth and sediment characteristics. The forcing conditions can be full time series or statistical distributions of waves and currents. Events can be run in sequence or in random order. Changes in bed elevation and sediment distribution at each node are calculated from the divergence of net flux for a transport event. Bed sediment fractions are calculated based on an active layer depth using the equations of Cui and Parker (1998). If a greater volume of sediment is eroded than is present in the active layer at a node, then the erosion depth, fluxes and fractions are adjusted to just remove all of that size fraction from the active layer; downflux nodes affected by these adjustments are also updated. Fractions are then recalculated based on a 10-cm thick bioturbated surface layer and one deeper exchange layer (now extending to 30 cm). Updated fractions and bed elevations are used as input for next event.

Initial runs of the model have been made for the S-line of the Eel shelf using currents from S-60, depth-dependent wave conditions based on data from NOAA Buoy 46022, and sediment from Drake's grain size analysis. The model is stable and conserves mass, however it is very sensitive to the sediment flux specified at the shoreward boundary of the inner shelf. Similar difficulties have been encountered in other cross-shelf models. An approach in which the shoreward sediment flux is related

to the input of sediment from the Eel River is currently being investigated. A means of connecting the shelf to the shoreline is also necessary for the model to operate in SEDFLUX. Approaches for accomplishing this are also being considered. The model has been formulated in a manner that facilitate incorporation into SEDFLUX and the SEDLUX modeling group is currently implementing the model in SEDFLUX.

The simple shelf model under development with Pratson and Paola is based on the depositional potential of sediment delivered to the shelf. Depositional potential depends on the ratio of bed shear stress (dominated by wave effects) to the critical shear stress for sediment motion. Sediment delivered to the shelf is deposited at depths across the shelf depending on the depositional potential and the ratio of settling to advection. Minimum water depth is determined as the depth at which wave-generated bottom stresses equal the critical shear stress for sediment motion. A notable characteristic of the resulting margins is a shelf of constant depth seaward of the near-shore zone. Processes that might contribute to the development of shelf depths that increase toward the shelf edge include wave shoaling, sediment compaction and subsidence. Calculations of the effects of wave shoaling show that this is not important on the mid and outer shelf. Effects of compaction and subsidence on shelf slope depend on the time scale of these processes relative to the time scale of sediment delivery.

Analysis of decadal and longer time-scale variations in forcing

Calculations of shelf sediment transport over time frames longer than the existing record of waves and currents require us to extend our knowledge of forcing conditions based on available data to the time scales of our calculations. One way to accomplish this is to relate interannual and long-term changes in local storm forcing to larger-scale atmospheric circulation changes. A proof of concept has been established by a preliminary analysis of daily averaged values of atmospheric wind speed and sea level pressure (SLP) data from 1982-1999 from NOAA NDBC Buoy 46022 on the Eel River margin. Some small gaps in the daily data have been infilled for the purpose of the analysis. Missing SLP data have been filled by persistence of neighboring values. Missing daily wind data have been infilled through assigning random daily values (based on climatological mean and variance of the log-normally transformed wind data). This imposes the climatologically expected variance structure for the missing daily wind data, which is necessary for an unbiased estimate of trends and variability in wind variance in the presence of modest data gaps.

An excellent correspondence is observed (Figure 1) between cold-season mean SLP and cold-season mean wind variance for this particular site. The linear correlation ($r=-0.6$) is significant at the $p=0.005$ level under the assumption of a negative relationship between SLP and wind variance (such a relationship is dictated by our *a priori* assumption that low atmospheric surface pressure is associated with enhanced storm activity at the seasonal timescale, since a positive relationship would be physically inconsistent). Since the local SLP variations are coherent with larger-scale atmospheric circulation variability in the Pacific Northwest region (for example, the large negative SLP excursions in winter 1982/1983 and 1997/1998 shown are associated with exceptionally large *El Nino* events), it thus appears for this particular site that at least 1/3 of the year-to-year variance in the amplitude of cold-season synoptic timescale wind forcing at the site level is associated with interannual large-scale atmospheric circulation variations. It is noteworthy that not only is the interannual variability coherent, but so are the decadal trends in wind variance and SLP. The latter is promising for the next stage in our analysis, which involves using NCEP reanalysis SLP and wind data for the greater Pacific Northwest region to constrain the spatial relationship between large-scale SLP and local synoptic wind

variance over a multidecadal time period. Once this relationship is calibrated, it can be applied to longer-term gridded instrumental SLP data over the past century and paleoreconstruction of large-scale annual cold-season SLP variations in the Pacific Northwest during the past few centuries (e.g., Biondi et al, 1999; M. Hughes pers. Comm.) to derive a long-term synoptic storm forcing series to drive models of coastal sedimentation.

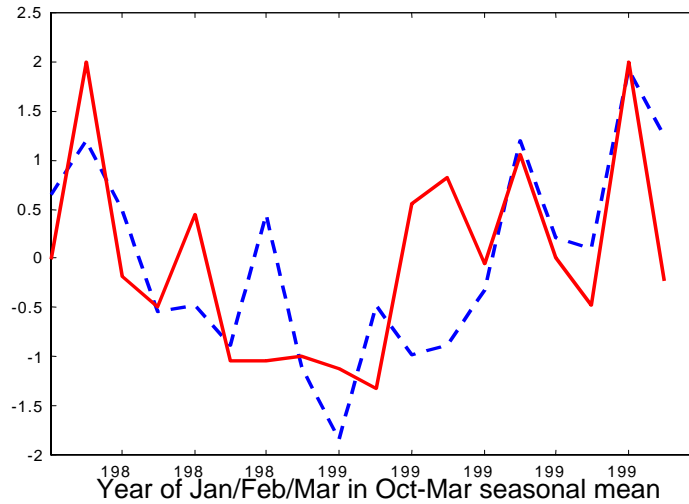


Figure 1. Negative standardized cold-season mean sea-level pressure anomaly (red-solid) plotted with the standardized cold-season mean wind variance anomaly (blue-dashed). Cold season is defined as Oct-Mar. The correlation between the two signals ($r=0.6$) is significant.

Application of the resuspension-flocculation-consolidation model for fine-grained shelves

We have developed a coupled, time-dependent model that includes wave-current interactions, resuspension, flocculation and consolidation. Application of the model shows that consolidation limits entrainment rates while flocculation increases particle settling rates. Both processes tend to reduce particle concentrations in the water column compared to suspensions of disaggregated, unconsolidated sediment. The flocculation state of a sediment suspension varies in response to changes in suspended sediment concentration and shear velocity, making particle settling rates a function of flow conditions and entrainment rates. Concentrations in excess of ~25 mg/l result in suspensions that are largely flocculated. As wave and current speeds increase, the time required to reach steady state decreases owing to more rapid floc formation. At low wave speeds (<10-20 cm/s), the steady-state suspension includes no flocs. The consolidation state of a sediment bed increases with time and depth below the bed surface, and is accompanied by increases in the critical shear stress for entrainment.

The effects of flocculation and consolidation are illustrated in a model run for the S-60 tripod site on the Eel shelf during October, 1995 (Ogston and Sternberg, 1999). Calculated suspended sediment concentration, floc percentage, and bed reworking depth are shown in Figure 2. Total mass in suspension is ~2 times lower than in calculations without flocculation or consolidation. Floc percentages vary with flow condition, reaching maximum values as flow conditions begin to wane after a resuspension event (3rd panel). Consolidation decreases the total depth of bed reworking (green and orange bands in 4th panel), but armoring of the bed is more significant in limiting erosion in this

example. Flocculation produces deposits with size distributions reflective of the original distribution. Without flocculation, a surface graded bed develops.

Measured suspended sediment concentrations at site S-60 on the Eel shelf were higher during and shortly after major river discharge events than during similar wave conditions when river discharge was low. Average suspended sediment concentrations 30 cm above the bed were ~ 2 times higher after the January 1997 flood than before. Seabed measurements show that the flood resulted in a fine-grained deposit > 5 cm thick at S-60 (Wheatcroft and Borgeld, 2000). Suspended sediment concentrations were calculated for the same time period assuming (a) a consolidated 'mature' bed (size distribution taken from winter 1995 analysis at S-60); and (b) an unconsolidated flood bed in which all sediment is $< 20 \mu\text{m}$ in size (Drake, 1999); flocculation was included in both cases. Good agreement between calculated and observed concentrations indicate that the difference in observed concentrations before and after the flood can be largely explained by the differences in bed properties.

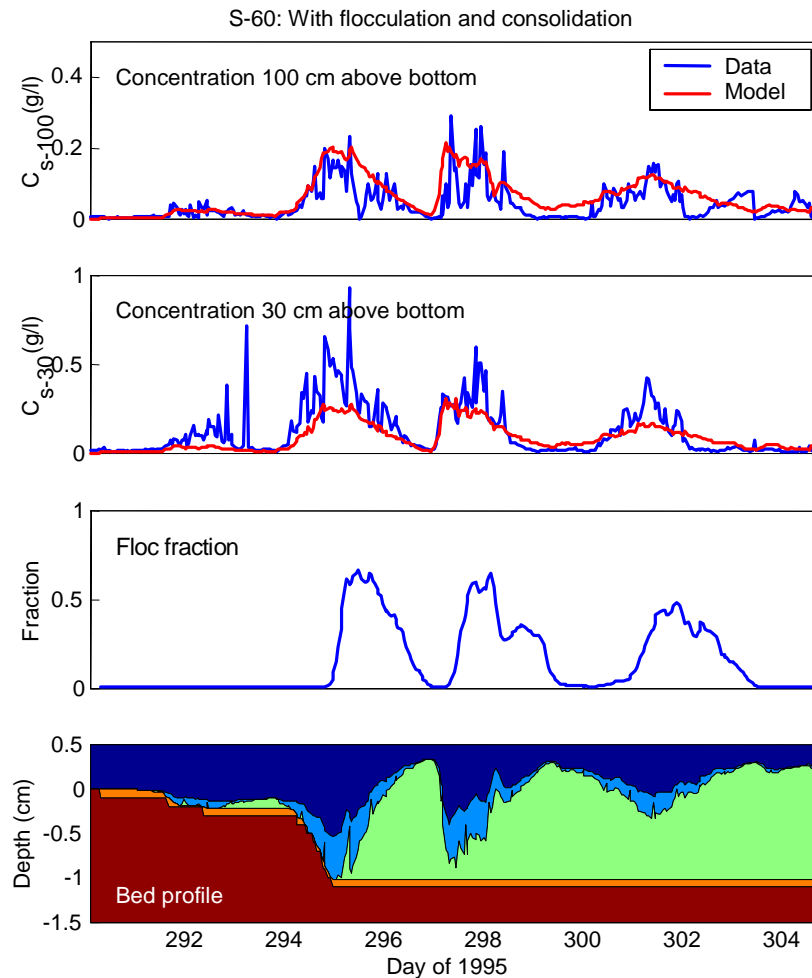


Figure 2. Calculated suspended sediment concentrations, floc percentage and bed profile for an initially consolidated bed at S-60 on the Eel shelf.

IMPACT/APPLICATION

The representations of shelf processes developed in this work will improve margin sedimentation models such as SEDFLUX and SEQUENCE.

TRANSITIONS

The distributed 1D cross-shelf sediment transport model is being incorporated into SEDFLUX.

RELATED PROJECTS

Representing shelf processes in long-term stratigraphic models is related to efforts in the Geoclutter program to model the evolution of continental shelf morphology, particularly the formation and filling of channels, under conditions of varying sea level. Understanding and characterizing effects of flocculation and consolidation will be important in modeling other fine-grained environments such as the Adriatic, a focus site of the EuroSTRATAFORM program.

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